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# Thermal Requirements of the Early Life History Stages of Walleye, 'Stizostedion vitreum vitreum' and Sauger, 'Stizostedion canadense'

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16. ABSTRACT

Walleye (Stizostedion vitreum vitreum) and sauger (Stizostedion canadense) eggs were exposed to temperatures ranging from 6 to 21 C to determine temperature effects on fertilization, incubation, and fry survival. Optimum fertilization temperatures were 6-12 C for walleye and 9 C for sauger. Optimum incubation temperatures were 9-15 C for both walleye and sauger. A sharp drop or rise in temperature had no great effect on walleye fry and juvenile survival. Optimum temperature for juvenile walleye and sauger growth was 22 C. When acclimated at 8-26 C, 96-h upper lethal temperatures for walleye juveniles were 27.0-31.6 C, with the lower acclimation temperatures producing the lower upper lethal limits and intermediate acclimation producing intermediate upper lethal limits in order as acclimation temperatures increased. When acclimated at 10-26 C, the 96-h upper lethal temperatures for sauger juveniles was 26.6-30.4 C, in order as with the walleye.

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# Thermal Requirements of the Early Life History Stages of Walleye, *Stizostedion vitreum vitreum*, and Sauger, *Stizostedion canadense* [1]

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KOENST, W. M., AND L. L. SMITH JR. 1976. Thermal requirements of the early life history stages of walleye, *Stizostedion vitreum vitreum*, and sauger, *Stizostedion canadense*. J. Fish. Res. Board Can. 33: 1130–1138.

Walleye (*Stizostedion vitreum vitreum*) and sauger (*Stizostedion canadense*) eggs were exposed to temperatures ranging from 6 to 21 C to determine temperature effects on fertilization, incubation, and fry survival. Optimum fertilization temperatures were 6–12 C for walleye and 9 C for sauger. Optimum incubation temperatures were 9–15 C for both walleye and sauger. A sharp drop or rise in temperature had no great effect on walleye fry and juvenile survival. Optimum temperature for juvenile walleye and sauger growth was 22 C. When acclimated at 8–26 C, 96-h upper lethal temperatures for walleye juveniles were 27.0–31.6 C, with the lower acclimation temperatures producing the lower upper lethal limits and intermediate acclimation producing intermediate upper lethal limits in order as acclimation temperatures increased. When acclimated at 10–26 C, the 96-h upper lethal temperatures for sauger juveniles was 26.6–30.4 C, in order as with the walleye.

KOENST, W. M., AND L. L. SMITH JR. 1976. Thermal requirements of the early life history stages of walleye, *Stizostedion vitreum vitreum*, and sauger, *Stizostedion canadense*. J. Fish. Res. Board Can. 33: 1130–1138.

Nous avons exposé des œufs de doré jaune (*Stizostedion vitreum vitreum*) et de doré noir (*Stizostedion canadense*) à des températures allant de 6 à 21 C en vue de déterminer les effets de la température sur la fécondation, l'incubation et la survie des alevins. Les températures optimales de fécondation sont de 6–12 C pour le doré jaune et de 9 C pour le doré noir. Les températures optimales d'incubation sont de 9–15 C pour les deux espèces. Un abaissement ou une élévation soudaine de la température n'a pas grand effet sur la survie des alevins et des jeunes dorés jaunes. La température optimale de croissance des jeunes dorés jaunes et dorés noirs est de 22 C. Chez des jeunes dorés jaunes acclimatés à des températures de 8 à 26 C, les températures létales supérieures après 96 h sont de 27.0–31.6 C, les plus basses températures d'acclimatation produisant des limites supérieures plus basses, et une acclimatation intermédiaire produisant des limites létales supérieures intermédiaires, augmentant en fonction de l'augmentation des températures d'acclimatation. Pour des jeunes dorés noirs acclimatés à des températures de 10 à 26 C, la température létale supérieure après 96 h est de 26.6–30.4 C, dans le même ordre que chez le doré jaune.

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THE determination of temperature effects on early life history stages of walleye, *Stizostedion vitreum vitreum*, and sauger, *Stizostedion canadense*, is necessary to establish thermal criteria for these species. Many authors have reported that walleye spawning occurs at 6–12 C (Bradshaw and Muir 1960; Eschmeyer 1950; Johnson 1961; Niemuth et al. 1959; Payne 1964; Priegel 1970; Rawson 1957; Schumann 1964). Others have reported that sauger spawn at the same temperature range as the walleye (Carufel 1963; Nelson 1968; Priegel 1969). Priegel (1968) reported that walleye eggs will hatch in 21 days at 10–12 C while saugers will hatch in 13–15 days at these temperatures. Various authors have reported thermal effects on egg survival. Steucke (1968) concluded that the apparent optimum temperature range for hatching walleye eggs is 16.7–19.4 C. Furthermore, it was pointed out by Allbaugh and Manz (1964) that temperature fluctuations during incubation of walleye eggs had no great effect on percentage hatch. Johnson (1961) showed that best egg survival in natural condi-

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tions occurred in years of warmwater temperatures and shortened incubation periods.

The present studies were designed to determine: 1) optimum temperatures for fertilization, incubation, and fry survival; 2) optimum temperatures for juvenile growth; 3) effects of a sudden temperature change on fry and juveniles; 4) upper lethal temperatures for juveniles with different acclimation temperatures.

## Materials and Methods

### Experimental Fish Stock

Adult walleyes were secured from Little Cut Foot Sioux Lake and Upper Red Lake in the spring of 1971 and 1972. Adult saugers were taken from Lake Winnebago, Wisconsin in 1972 and from the Mississippi River below Lock and Dam no. 3 in Red Wing during the spring of 1972 and 1973. Juvenile walleyes were secured in July and August of 1971 and 1972 from natural rearing ponds stocked by the Minnesota Department of Natural Resources. Juvenile saugers were collected from Lake Pepin, Minnesota, during the months of July and August 1973.

### Experimental Apparatus

Apparatus included six polyethylene head tanks, each equipped with immersion heaters regulated by a thermostat. Each head tank fed water to a set of experimental incubation, fry, and juvenile chambers. It was possible to maintain temperatures in the experimental chambers within a range of ±0.2–0.3 C (SD = 0.26) of the desired temperature.

Eggs were tested in 10 × 3.8-cm acrylic cylinders. Five centimeters from the top of the cylinders the eggs lay on Nitex screen where water flow averaged 325 ml/min (range 200–425 ml/min). The cylinders were submerged in 13.5 × 10.5 × 20-cm glass cases with one side of no. 656 Nitex screen. These cases were placed in larger aquaria so that the cylinders were submerged but not the top of the cases. This arrangement allowed the fry to swim out of the incubation cylinders and be removed to larger chambers. Fry test chambers were 25-liter glass aquaria with a flow-through rate of 1 liter/min (±100 ml). Juveniles were tested in chambers of the same size with flow-through rates varying from 1 to 2 liters/min, depending on test temperatures. Each chamber was lighted with a 40-W incandescent light placed 0.5 m from the water surface and photoperiod was adjusted bimonthly to simulate natural day length. Test water from the laboratory well had a pH of 7.5 at 10 C and an analysis described by Adelman and Smith (1972).

### Acclimation Procedure

Adult fish taken in the field at 5–10 C were acclimated to six test temperatures (6, 9, 12, 15, 18, and 21 C). They were held at temperature of capture for 12 h and then raised to test temperature in 24 h where they were held for 24–48 h before eggs were stripped. Juvenile fish captured in the field at 18–24 C were adjusted to test temperature at a rate of 2 C/day and held for a minimum of 14 days before each test.

### Egg Tests

Adult fish were stripped and eggs were fertilized at the temperature to which the adults were acclimated. Eggs from two females were stripped into a Nalgene beaker, and milt from two males and water at test temperature were added a few seconds later. Bentonite clay was then added to prevent clumping. The eggs were rinsed clean and the beaker was held at test temperatures until eggs had water hardened. Within 1 h after fertilization 100–300 pooled eggs were randomly removed with an eye dropper and placed in the incubation chambers. Small and opaque eggs were discarded. The number of opaque eggs varied from 0 to 80% with no relation to temperature of fertilization. Dead eggs were removed daily and live eggs were not handled during incubation.

Upon hatching, 10% of the fry from each day's hatch were randomly removed and preserved in 5% formalin and 100 fry were placed in each fry test chamber. All fry were fed twice a day with natural plankton, which consisted mostly of copepods, and once a day with brine shrimp.

### Experimental Design

To separate the effects of temperature at fertilization and during incubation on hatchability, eggs fertilized at each temperature were incubated and fry carried to the juvenile stage at six temperatures (6, 9, 12, 15, 18, and 21 C). Statistical analysis was done by two-way analysis of variance followed by Duncan's multiple range test (Steel and Torrie 1960). Optimum temperature for juvenile growth was determined in tests running for 28 days with walleye and 36 days with sauger. All tests consisted of two replicates with 10 fish in each. Fish were fed an excess of small fathead minnows (*Pimephales promelas*). One-way analysis of variance was the statistical procedure for growth followed by Duncan's multiple range test.

To determine the effect of sudden temperature changes on fry and juveniles, fish were transferred directly from one temperature to another. The control consisted of fish submitted to the same transfer procedure but without temperature change. The percentage survival in the treatments was corrected to survival in controls. Tests for fry were conducted for 72 h and for juveniles for 96 h. The shorter fry test removed the factor of potential starvation.

Upper lethal temperature tests were conducted on juvenile walleyes with a mean length of 115 mm. All fish were acclimated for 2 wk and then 10 fish were placed in each of three 25-liter flow-through chambers at the acclimation temperature for 2 days prior to each test. Temperatures were then raised to the experimental temperatures at a rate of 3–4 C/h. The fish were not fed for 96 h prior to testing. Juvenile saugers (mean length 119 mm) in groups of 24 were acclimated in 25-liter aquaria for 2 wk prior to each

TABLE 1. Percentage hatch of walleye (*Stizostedion vitreum vitreum*) eggs fertilized and incubated at different temperatures.

| Fertilization temp (*C*) | Incubation temp (*c*) | | | | | |
|---|---|---|---|---|---|---|
| | 6.0 | 8.9 | 12.0 | 15.0 | 18.1 | 20.9 |
| 6.2 | 84.0 | 77.0 | 77.0 | 80.0 | 63.0 | 0.0 |
| 9.1 | 51.0 | 66.5 | 67.0 | 73.0 | 61.0 | 23.0 |
| 12.0 | 37.7 | 59.0 | 61.5 | 53.0 | 38.0 | 10.0 |
| 15.2 | 5.0 | 11.0 | 15.0 | 15.0 | 0.0 | 0.0 |
| 17.9 | 11.0 | 39.0 | 27.0 | 41.0 | 32.0 | 1.0 |
| 20.9 | 1.0 | 5.0 | 10.0 | 7.0 | 0.0 | 0.0 |

TABLE 2. The effect of six different temperatures on walleye eggs and fry[a] held at a constant temperature during fertilization, incubation, and after hatching.

| Temp (*C*) | Egg survival[b] (%) | Abnormal fry (%) | Days to first hatch | Days to median hatch | Days to completion hatch | Mean size at hatch (*mm*) | Survival of sac fry[c] (%) | Survival to juvenile stage[d] (%) |
|---|---|---|---|---|---|---|---|---|
| 6.0 | 84.0 | 1.0 | 30 | 34 | 49 | 6.0 | 0 | 0 |
| 8.9 | 66.5 | 3.8 | 23 | 27 | 31 | 7.3 | 78 | 0 |
| 12.0 | 61.5 | 3.3 | 12 | 15 | 18 | 7.8 | 88 | 0 |
| 15.0 | 15.0 | 1.0 | 8 | 10 | 11 | 7.2 | 95 | 0 |
| 18.1 | 32.0 | 15.0 | 6 | 7 | 8 | 7.2 | 97 | 1 |
| 20.9 | 0.0 | 18.0 | 5[e] | 5[e] | 6[e] | 6.6[e] | 98[e] | 8[e] |

[a]Fry data were determined from 100 hatched fry that were taken at random from the total hatch at each temperature. Abnormal fry were not included.
[b]200 eggs tested at each temperature.
[c]Sac fry stage was considered to be from hatch to disappearance of yolk sac.
[d]Fish denoted as juveniles when they reached a length of 40 mm.
[e]Data obtained from fry hatched from eggs incubated at 21 C but fertilized at 9 and 12 C.

test. After acclimation the fish were randomly divided into three groups of eight fish. Upper lethal tests for saugers were conducted on the basis of a sudden thermal change as described in the previous section.

## Results

### EFFECT OF TEMPERATURE ON WALLEYE HATCH

The highest percentage hatch in the range of incubation temperatures resulted from fertilization at 6, 9, and 12 C (Table 1). As the fertilization temperature increased, the percentage hatch at all incubation temperatures decreased with the lowest hatch resulting from fertilization at 21 C. There was no significant difference between the percentage hatch at fertilization temperatures of 6, 9, and 12 C ($P < 0.05$). There was a significant difference between the three lower fertilization temperatures and the three higher temperatures. No significant difference was found between fertilization temperatures of 15 and 21 C. Independent of the effect of fertilization temperature, the greatest overall mean percentage hatch was at incubation temperatures of 9–15 C and the lowest at 21 C. There was no significant difference found in the percentage hatch between the incubation temperatures of 9–15 C ($P < 0.05$).

Walleye fry survival, days to hatch, and size of fry at hatch were determined with temperature held constant at all stages (Table 2). Incidence of abnormal fry increased with increase in incubation temperature. The percentage of abnormal fry was 1.0–3.8% at temperatures from 6 to 15 C and increased to 15 and 18% at 18 and 21 C, respectively. Abnormal fry were included in total hatch. Time to first hatch, median hatch, and completion of hatch were longest at 6 C and decreased exponentially with increased temperature. The mean size of fry at hatch varied from 6.0 mm at 6 C to 7.8 mm at 12 C. The mean size of fry at hatch was greatest (7.2–7.8 mm) at the intermediate temperatures, 9–18 C, and least at 6 and 21 C. Fry size at 9–18 C was significantly different from fry size at 6 and 21 C ($P < 0.05$). Survival of walleye fry from hatch to resorption of the yolk sac was high (78–98%) at all temperatures except at 6 C. Total survival of walleye fry from hatch to the juvenile stage was low.

TABLE 3. Growth of walleye juveniles at different temperatures over a 28-day period.

| Temp (C) | At start of test: mean length (mm) | At start of test: mean Wt (g) | Increase in: length (mm) | Increase in: Wt (g) | Specific growth rate (%/day) | Survival (%) |
|---|---|---|---|---|---|---|
| 18.1 | 84.2 | 4.3 | 25.8 | 6.5 | 3.29 | 100 |
| 20.2 | 84.6 | 4.6 | 31.6 | 8.1 | 3.64 | 100 |
| 22.1 | 85.5 | 4.6 | 36.1 | 9.6 | 4.01 | 100 |
| 23.9 | 85.7 | 4.7 | 32.6 | 7.8 | 3.48 | 80 |
| 26.0 | 85.2 | 4.4 | 29.3 | 6.7 | 3.29 | 80 |
| 28.0 | 86.5 | 4.9 | 23.7 | 5.2 | 2.55 | 80 |

At 6 C the yolk sac was not completely resorbed and fry eventually died about 30 days after hatching. The fry at 9 and 12 C never accepted food and died. Initially a few fry at 15 C accepted food, about 50% fed at 18 C, but none survived at the former temperature and 1% at the latter. At 21 C, where 8% of the fry lived to the juvenile stage, about 75% accepted food (Table 2).

### GROWTH OF WALLEYE JUVENILES

Growth of walleye juveniles was tested at 18, 20, 22, 24, 26, and 28 C (Table 3). Maximum growth was at 22 C where the juvenile fish increased 42.2% in length and 207.4% in weight in 28 days and had a specific growth rate of 4.01. Minimum growth occurred at 28 C where fish increased 27.4% in length, 104.3% in weight, and had a specific growth rate of 2.55. At 18 and 26 C the growth rates were identical. Although the percentage gain in length at 18 C (30.6%) differed from 26 C (34.4%), the specific growth rate was 3.29 and the percentage gain in weight was 150.7% for both temperatures. The rate of increase in the specific growth rate between 18 and 22 C was equal to the rate of decrease between 22 and 26 C. There was a significant difference in growth between 22 C and the other five temperatures ($P < 0.05$) and between 26 and 18 C. Growth at 28 C was significantly different from all the other temperatures.

### EFFECT OF SUDDEN TEMPERATURE CHANGE ON WALLEYE

Walleye fry hatched and acclimated at 6, 11, and 21 C were subjected to sudden temperature changes (Table 4). Fry mortality in 72 h was observed at immediate temperature changes of +15 C from 6 to 21 C, −5 C where a change of 11–6 C was effected, and −15 C where fry acclimated to 21 C were exposed to a temperature of 6 C. No large mortality was observed at other temperatures.

TABLE 4. Effects of temperature change in 72 h on walleye fry after incubation and rearing at 6, 11, and 21 C.

| Rearing temp[a] (C) | Test temp (C) | Survival (%) | Corrected survival[b] (%) |
|---|---|---|---|
| 6.0 | 6.0 | 90 | 100 |
| 6.0 | 11.1 | 90 | 100 |
| 6.0 | 15.9 | 100 | 111 |
| 6.0 | 21.1 | 50 | 56 |
| 11.1 | 11.1 | 98 | 100 |
| 11.1 | 15.9 | 100 | 102 |
| 11.1 | 21.1 | 76 | 78 |
| 11.1 | 6.0 | 56 | 58 |
| 21.1 | 21.1 | 66 | 100 |
| 21.1 | 6.0 | 0 | 0 |
| 21.1 | 11.1 | 60 | 91 |
| 21.1 | 15.9 | 72 | 109 |

[a]Age of fry was 5 days at 6 C, 2 days at 11 C, and 7 days at 21 C.

[b]Control corrected to 100% and other temperature levels adjusted accordingly.

Juvenile walleyes (80–100 mm in length) acclimated to various temperatures were exposed to immediate temperature changes (+12 to −17 C) and held at the new temperature over a 96-h period. Only when walleye juveniles acclimated to 25 C were chilled −17 to 8 C were detrimental effects observed. Mortalities in this group reached 30%. No mortality occurred between temperature changes of −13 and +12 C.

### WALLEYE UPPER LETHAL TEMPERATURE

Upper lethal temperatures were determined for walleye juveniles acclimated to temperatures ranging from 8 to 26 C by 2 C intervals (Table 5). Fish were tested for 96 h only since mortality occurred mostly within the first 12 h of the test. The upper lethal temperature is the incipient lethal temperature which Fry (1947) defined as the temperature at which 50% or more of the

TABLE 5. Percentage survival of walleye juveniles exposed to upper lethal temperature levels for each acclimation temperature for 96 h.

| Acclimation temp (C) | Test temp (C) | | | | | | | | TL50 (C) |
|---|---|---|---|---|---|---|---|---|---|
| | 26.0 | 27.0 | 28.0 | 29.0 | 30.0 | 31.0 | 32.0 | 33.0 | |
| 8.0 | 100 | 50 | 10 | — | — | — | — | — | 27.0 |
| 10.1 | — | 100 | 100 | 10 | — | — | — | — | 28.6 |
| 12.1 | — | — | 100 | 50 | 0 | — | — | — | 29.0 |
| 13.9 | — | — | — | 90 | 10 | 0 | — | — | 29.5 |
| 16.0 | — | — | — | 100 | 100 | 10 | — | — | 30.6 |
| 18.2 | — | — | — | 100 | 100 | 0 | — | — | 30.5 |
| 20.2 | — | — | — | — | 100 | 0 | 0 | — | 30.5 |
| 22.1 | — | — | — | — | 100 | 0 | 0 | — | 30.5 |
| 24.0 | — | — | — | — | — | 90 | 10 | — | 31.5 |
| 25.8 | — | — | — | — | — | 100 | 10 | 0 | 31.6 |

TABLE 6. Percentage hatch of sauger (*Stizostedion canadense*) eggs fertilized at four temperatures and incubated at six temperatures.

| Fertilization temp (C) | Incubation temp (C) | | | | | |
|---|---|---|---|---|---|---|
| | 6.0 | 8.9 | 12.0 | 15.0 | 18.1 | 20.9 |
| 9.2 | 46.2 | 72.2 | 75.7 | 77.8 | 80.4 | 65.7 |
| 11.9 | 1.7 | 14.8 | 32.0 | 27.2 | 2.2 | 0.0 |
| 15.0 | 2.0 | 34.0 | 77.0 | 73.5 | 12.0 | 1.0 |
| 18.2 | 0.0 | 25.5 | 58.6 | 54.0 | 44.5 | 42.0 |

fish died. The upper lethal temperature increased as the acclimation temperature increased. From acclimation temperatures of 8–26 C, incipient lethal temperature increased from 27.0 to 31.6 C. In most cases there was a temperature difference of 1 C between 90 and 100% survival and 0 and 10% survival.

## TEMPERATURE EFFECTS ON SAUGER EGGS AND FRY

Sauger eggs fertilized at 9, 12, 15, and 18 C were incubated at 6, 9, 12, 15, 18, and 21 C (Table 6). Fertilization at 9 C resulted in the highest percentage hatch for each incubation except 12 C where eggs fertilized at 15 C had a slightly higher but not significant ($P < 0.05$) percentage hatch (77.0%) than at 9 C (75.7%). The percentage hatch decreased as the fertilization temperature increased. There was a significant difference ($P < 0.05$) between fertilization at 9 C and fertilization at the other temperatures. There was no significant difference between fertilization temperatures of 15 and 18 C and fertilization at 12 C was significantly different from the rest. Egg survival was greatest at incubation temperatures from 9 to 15 C, regardless of the fertilization temperature. There was no significant difference ($P < 0.05$) in the percentage hatch between incubation temperatures of 9–15 C. No significant difference was noted between incubation temperatures of 9, 18, and 21 C. Survival at incubation temperature of 6 C was significantly different from the rest.

Sauger eggs and fry were held in six constant temperatures through fertilization, incubation, hatch, and growth to the juvenile stage. Survival of eggs, sac fry, and juveniles, time to hatch, and size of fry at hatch were determined (Table 7). Incidence of abnormalities in hatched fry increased as the temperature increased but the percentage of abnormalities at 18 C was not significantly different from 6, 9, and 12 C ($P < 0.05$). Abnormal fry were included in total percentage hatch figures. Time to first hatch, median hatch, and total hatch increased as the temperature decreased. The mean size of the fry was least at 6 C (4.77 mm) but did not vary significantly ($P < 0.05$) at the other temperatures (5.58–5.84 mm). Survival of sauger fry from hatch to the disappearance of the yolk sac was high for all temperatures except 6 C where fry did not resorb the yolk sac before dying. Survival of fry from hatch to juvenile stage was low at all temperatures. Fry at the higher temperatures fed well while fry at the lower temperatures did not accept

TABLE 7. The effect of six constant temperatures on sauger eggs and fry[a].

| Temp (C) | Egg survival[b] (%) | Abnormal fry (%) | Time to first hatch (days) | Time to median hatch (days) | Time to completion hatch (days) | Mean size at hatch (mm) | Survival of sac fry[c] (%) | Survival to juvenile stage[d] (%) |
|---|---|---|---|---|---|---|---|---|
| 6.0 | — | 2.0[e] | 37[e] | 45[e] | 58[e] | 4.77[e] | 0[e] | 0[e] |
| 8.9 | 72.2 | 2.0 | 22 | 28 | 35 | 5.76 | 92 | 0 |
| 12.0 | 32.0 | 3.5 | 12 | 16 | 21 | 5.84 | 86 | 0 |
| 15.0 | 73.5 | 18.0 | 8 | 10 | 13 | 5.58 | 75 | 0 |
| 18.1 | 44.5 | 3.3 | 7 | 8 | 10 | 5.64 | 90 | 1 |
| 20.9 | — | 23.0[e] | 5[e] | 6[e] | 8[e] | 5.59[e] | 85[e] | 8[e] |

[a]Fry data were determined from 100 hatched fry taken at random from the total hatch at each temperature. Abnormal fry were not included.
[b]200 eggs were tested at each temperature.
[c]Sac fry stage was considered to be from hatch to the disappearance of yolk sac.
[d]Fish were determined to be juveniles when they reached a length of 40 mm.
[e]Data from fry fertilized at 9–18 C but incubated at 6 and 21 C.

TABLE 8. Growth of sauger juveniles at different temperatures for a 36-day period.

| Temp (C) | At start of test: mean length (mm) | At start of test: mean Wt (g) | Increase in: length (mm) | Increase in: Wt (g) | Specific growth rate (%/day) | Survival (%) |
|---|---|---|---|---|---|---|
| 16.1 | 96.0 | 5.9 | 13.5 | 3.1 | 1.16 | 100 |
| 18.1 | 93.5 | 5.3 | 19.0 | 4.2 | 1.62 | 100 |
| 20.0 | 95.5 | 5.8 | 16.5 | 3.7 | 1.36 | 90 |
| 22.0 | 96.0 | 5.6 | 22.0 | 5.4 | 1.89 | 100 |
| 26.0 | 99.0 | 6.4 | 13.5 | 3.5 | 1.20 | 60 |

food. Fry mortality was apparently caused by starvation, since temperature was the trigger mechanism to feeding for fry held in captivity under laboratory conditions.

### GROWTH OF JUVENILE SAUGERS

Optimum temperature for growth of sauger juveniles was determined for a series of temperatures ranging from 16 to 26 C at 2 C intervals (Table 8). Maximum growth was at 22 C and minimum growth at 16 C. Growth at 22 C was significantly different ($P < 0.05$) from growth at all other test temperatures. Growth at the other test temperatures was not significantly different.

### UPPER LETHAL TEMPERATURES FOR SAUGER JUVENILES

Upper lethal temperatures (Table 9) and median survival times (Table 10) were determined for sauger juveniles acclimated to temperatures ranging from 10 to 26 C by 2 C intervals. Fish were tested for 96 h. The upper lethal temperature increased as the acclimation temperature increased. With acclimation temperatures of 10–26 C, upper lethal temperatures increased from 26.6 to 30.4 C. In most cases there was a sharp decrease in survival with a 1 C rise in temperature and a marked decrease in median survival time with a 1 C increase.

## Discussion

The results of this investigation show that temperature has an important impact on walleye and sauger eggs, fry, and juveniles. The optimum temperatures and lethal temperatures vary significantly for different life history stages with the optima for fertilization, incubation, and fry survival gradually increasing in the successive stages. The optimum temperature ranges for fertilization, incubation, and fry survival of walleyes are 6–12, 9–15, and 15–21 C, respectively. The optimum temperatures for the same stages in sauger are 9–15, 12–15, and 15–21 C, respectively. These ranges correspond closely to the temperatures found in nature when the various stages are present. Under normal conditions adult sauger and walleye spawn at temperatures of 6–12 C

TABLE 9. Percentage survival of sauger juveniles acclimated to 10–26 C and exposed to higher temperatures for 96 h.

| Acclimation temp (C) | Temp (C) | | | | | | | | TL50 (C) |
|---|---|---|---|---|---|---|---|---|---|
| | 25.0 | 26.0 | 27.0 | 28.0 | 29.0 | 30.0 | 31.0 | 32.0 | |
| 10.1 | 100 | 100 | 12.5 | — | — | — | — | — | 26.6 |
| 12.0 | — | 100 | 25.0 | 0 | — | — | — | — | 26.7 |
| 13.9 | — | — | — | 87.5 | 0 | 12.5 | — | — | 28.4 |
| 16.0 | — | — | — | 100 | 12.5 | 0 | — | — | 28.6 |
| 18.3 | — | — | — | 100 | 25.0 | 0 | — | — | 28.7 |
| 19.9 | — | — | — | — | 100 | 0 | 12.5 | — | 29.5 |
| 22.0 | — | — | — | — | 100 | 25.0 | 12.5 | — | 29.9 |
| 23.9 | — | — | — | — | — | 87.5 | 0 | 0 | 30.4 |
| 25.8 | — | — | — | — | — | 87.5 | 0 | 0 | 30.4 |

TABLE 10. Median survival time (minutes) of juvenile saugers acclimated to 10–26 C and exposed to upper lethal temperatures.

| Acclimation temp (C) | Test temp (C) | | | | | |
|---|---|---|---|---|---|---|
| | 27.0 | 28.0 | 29.0 | 30.0 | 31.0 | 32.0 |
| 10.1 | 114 | — | — | — | — | — |
| 12.0 | 260 | 68 | — | — | — | — |
| 13.9 | — | — | 32 | 16 | — | — |
| 16.0 | — | — | 29 | 18 | — | — |
| 18.3 | — | — | 31 | 19 | — | — |
| 19.9 | — | — | — | 1328 | 122 | — |
| 22.0 | — | — | — | 1512 | 545 | — |
| 23.9 | — | — | — | — | 1242 | 348 |
| 25.8 | — | — | — | — | 690 | 246 |

with the temperature gradually rising to 15 C by the time eggs hatch. Fry development takes place at 15–21 C. On the basis of studies reported here temperature regimes must be considered as an important factor in the establishment of year-classes and maintenance of populations in natural waters.

If unusually cold weather occurs after fry emergence, fry survival may be inhibited. Conversely, strong year-class may be dependent on gradual warming of water during egg deposition, incubation, and after fry emergence. Johnson (1961) stated that egg mortality, associated with unusually cold weather during the incubation period, may be an important factor in the limiting of the size of year-classes. Feeding of fry may also be reduced when temperatures are low. Fry fed well at the higher temperatures (18–21 C).

One discrepancy in the hatch data (Table 1) suggests that 15 C is more detrimental to egg survival than 18 C. It is believed that eggs fertilized at 15 C were of poor quality and less viable for an undetermined reason, but the egg mortality from this cause was consistent and independent of the incubation temperature or occurred before the incubation temperature had any effect. With the highest hatch at each fertilization temperature as a control (corrected to 100%), 15 C was a significantly better fertilization temperature than 18 C but significantly poorer than 12 C ($P < 0.05$). This discrepancy was also noted with saugers fertilized at 12 C (Table 6). It is believed that these eggs were also less viable for some reason other than temperature. When treated the same as the walleye eggs there was no significant difference found between 12 and 15 C ($P < 0.05$). Incidence of abnormal fry was affected by temperature. Both walleyes and saugers had substantial increases in abnormalities as the temperature increased. Optimum temperature for walleye growth was identical to the optimum temperature for sauger growth (22 C). The preferred temperature of fish according to Brett (1956) is also the optimum temperature for activity and growth, thus the preferred temperature for walleye and sauger juveniles is estimated to be 22 C. Proffitt (1969) and Merriman (1970) have noted the tendency for young fish to remain in warm water more than older and larger individuals. Kelso (1972) reported 20 C as the optimum tempera-

ture for growth of walleyes, age 2–6. Hile and Juday (1941) reported the preferred temperature of adult walleyes to be 20.6 C during summer months and Ferguson (1958) reported the preferred temperature of adult walleyes to be 22.7–23.2 C.

Walleye fry and juveniles acclimated to different temperatures were exposed to a sudden temperature change without severe mortality. It is apparent that the extent of temperature change is less important than the absolute temperature. If the temperature change is within the upper and lower tolerance limits, little or no mortality will occur. Mortality of fry from temperature change occurred only when fry hatched at 11 C were transferred to 6 C, a net change of −5 C, and when fry hatched at 21 C were transferred to 6 C, a change of −15 C. It appears that 6 C is a lethal temperature for fry hatched at 11 and 21 C, since fry hatched at 21 C and transferred to a temperature of 11 C, a change of −10 C, did not have high mortality.

Juvenile walleye exposed to a sudden temperature change showed a mortality only in fish acclimated to 25 C and dropped to 8 C, a change of −17 C, where loss was 30%. This suggests that 8 C is probably close to the lower lethal temperature of juveniles acclimated to 25 C. Tests done with saugers were upward shifts toward lethal temperatures so the effect of drops in temperature were not assessed. However, the extent of a sudden change in temperature did not harm fish until upper lethal temperature was approached. The upper lethal temperatures determined for walleye and sauger juveniles can be applied to juveniles only. The upper lethal temperature for larger fish may be slightly lower. Meuwis and Huets (1957) demonstrated this to be true for carp.

Results of the tests described herein suggest that temperature standards in natural waters must be adjusted for seasonal changes in requirements of the fish and that maximum temperatures not causing death are above the optimum levels for adequate population maintenance. Javaid and Anderson (1967) found that starvation influences the selected temperatures of salmonids. Probably the thermal tolerance is subject to the same influences, thus explaining the mortality that occurred at the higher temperatures in the growth study. Temperature maxima insuring natural population safety will probably be 3–4 C below the upper lethal temperature found for unfed fish.

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